industry on possible requirements for a research and innovation facility to support hydrogen use in industry and power.

By building our evidence base, and taking early action to support research and innovation, demonstration and deployment of low carbon hydrogen technologies in power, we can support further decarbonisation of the power sector by 2030 and for CB6 and help to establish a reliable, long term source of low carbon hydrogen demand.

2.4.3 Use of hydrogen in heat in buildings

Heating comprises 74 per cent of buildings emissions in the UK and about 23 per cent of all UK emissions.[53] While the electricity that powers our lighting and appliances is decarbonising fast, the majority of buildings still rely on fossil fuels – largely natural gas – for space heating, hot water and cooking. Meeting our net zero target by 2050 will therefore require us to switch to low carbon alternatives to heat the 30 million residential, commercial, industrial and public sector buildings in the UK.[54]

Given the scale of this challenge, it is essential that we start the transition now to meet our emissions reductions targets cost-effectively, minimise disruption, and ensure that households continue to enjoy a reliable and comfortable heating system. Over the 2020s and early 2030s, our aim is to move to only installing low carbon heat systems that are compatible with our net zero target, and we will keep pace with the natural replacement cycles of heating systems throughout the rest of the 2030s and into the 2040s. Our forthcoming *Heat and Buildings Strategy* will set out how we plan to decarbonise heat in buildings in the UK.

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How will we develop the potential use of hydrogen for heat over the 2020s?

While we are clear on the need to decarbonise heating to meet net zero, there is still a degree of uncertainty over the best route to decarbonising heat at scale in the UK. Low carbon hydrogen could be one of a few key options for decarbonising heat in buildings, alongside more established technologies such as electricity and heat networks. While there is more work to do to test the feasibility of using hydrogen, it could become a like-for-like alternative for buildings currently heated by natural gas from the grid.

We will need to be flexible in how we decarbonise heat in buildings given the diversity of heat demand across different building types and geographies in the UK. We are taking action to build heat pump and heat networks markets, especially in areas where we do not expect hydrogen to play a major role. Delaying action could prevent us from meeting near-term carbon budget and fuel poverty targets, making it harder to achieve our targets in later years.

Before hydrogen for heating can be considered as a potential option to decarbonise heat in buildings, we need to generate further evidence on the costs, benefits, safety, feasibility, air quality impacts and consumer experience of using low carbon hydrogen for heating relative to other more established heat decarbonisation technologies. The 2020s will be critical for understanding hydrogen's potential role, and government is working with industry, network operators and local partners on major studies and testing projects to help establish the evidence required.

Although we expect overall the demand for low carbon hydrogen for heating by 2030 to be relatively low (<1TWh), if the feasibility and positive case for hydrogen heating is established, heat in buildings could become a very significant source of future demand for hydrogen with implications for the design and timing of hydrogen production, storage and network infrastructure: our analysis suggests hydrogen demand for heat in buildings could be up to 45TWh by 2035.[55]

What are we doing to deliver?

A wide range of relevant work is already underway. For example, ongoing industry-led projects are exploring the distribution and transmission of hydrogen within gas networks, such as the HyNet project in the North West of England and H21 project on distribution across the North of England, and HyNTS and LTS Futures projects on transmission led by National Grid (see Chapter 2.3.1 for more detail). Additionally, the BEIS-funded £25m Hy4Heat programme, which is due to end this year, has supported the development and demonstration of '100 per cent hydrogen-ready' appliances and components. The Hy4Heat programme has also developed a framework for skills accreditation for heating engineers working with hydrogen.

As set out in the *Ten Point Plan*, **we are supporting industry to conduct first-of-a-kind hydrogen heating trials, including a neighbourhood trial by 2023 and a village scale trial by 2025.** The village trial will look to build on learning from the neighbourhood trial, involving a larger and more diverse range of consumers, and conversion of existing local area gas infrastructure to 100 per cent hydrogen.

The trials will provide evidence on the practical, logistical and technical issues involved in converting buildings and appliances. In particular, they will test and demonstrate how consumers experience the installation and use of hydrogen for heating in their homes and workplaces; the conversion, operation and performance of gas networks using hydrogen; and the skills and training required to deliver a conversion.

By 2025 we will also develop plans for a possible hydrogen heated town before the end of the decade. This planning work will also contribute important evidence on the feasibility and costs of converting from natural gas to hydrogen heating. We anticipate that if the case is made for wide scale conversion of the gas grid to full hydrogen, it would begin with converting a pilot town in the late 2020s and accelerate from the early 2030s, taking into account the practical implementation experience gained through the pilot.

The local trials and planning work, together with the results of our wider research and development and testing programme, will enable strategic decisions by 2026 on the role of hydrogen for heat and whether to proceed with the hydrogen town.

Case Study: hydrogen for heat in homes

H100 Fife Neighbourhood Trial: This Levenmouth, Fife-based project will deliver the world's first hydrogen-to-homes gas network in 2023. The trial will provide hydrogen to 300 homes for heating and cooking on an opt-in basis, switching from natural gas. The hydrogen used in these trials will be produced locally from offshore wind power. This ground-breaking project led by gas network SGN is collaboratively funded by SGN and its GDN partners Cadent, NGN and WWU, Ofgem and the Scottish Government. The H100 project will also provide evidence to assess consumers' experience of using hydrogen in the home and provide key learning on gas networks, such as constructing and operating a hydrogen network, that can be applied to future grid conversion projects.

We will continue to support research and innovation on hydrogen heating. Our new Net Zero Innovation Portfolio will allow further support to be directed towards innovation for end-users of hydrogen heating as needed, following on from Hy4Heat endpoints.

We are also accelerating work to consider how a market for hydrogen heating could operate, recognising the need to start adapting legislative and regulatory frameworks in advance of any strategic decisions being made on the role of hydrogen in heat. We are working with key regulators, including HSE and Ofgem, to ensure that we understand the regulatory changes, including timelines, that may be needed to roll out any future scenario for hydrogen heating.

Alongside wider market policy, we are actively considering the value of specific interventions to support the commercialisation of hydrogen heating products. **We aim to consult later this year on the case for enabling, or requiring, new natural gas boilers to be easily convertible to use hydrogen ('hydrogen-ready') by 2026.** We will also use this consultation to test proposals on the future of broader boiler and heating system efficiency and explore the best ways to reduce carbon emissions from our gas heating systems over the next decade.

Hydrogen has the potential to play a key role in decarbonising heat in buildings in the UK. We are rapidly delivering major studies and testing work to understand the feasibility of using hydrogen for heating, to inform broader strategic decisions in 2026 on heat decarbonisation.

2.4.4 Use of hydrogen in transport

Hydrogen is likely to be fundamental to achieving net zero in transport, potentially complementing electrification across modes of transport such as buses, trains and heavy goods vehicles (HGVs). It is also likely to provide solutions for sectors that will not be able to fully decarbonise otherwise, including aviation and shipping.

Low carbon hydrogen can provide an alternative to petrol, diesel and kerosene as it can be used directly in combustion engines, fuel cells and turbines or as feedstock for production of transport fuels, including ammonia and sustainable aviation fuels. We expect low carbon hydrogen to play a key role in decarbonising the sector, which is the largest single contributor to UK domestic GHG emissions and was responsible for 27 per cent of emissions in 2019.[56]

Transport is also a crucial early market for hydrogen, driving some of the earliest low carbon production in the UK. There are over 300 hydrogen vehicles on UK roads, mostly passenger cars and buses, and the government is supporting hydrogen use in transport with a **£23 million Hydrogen for Transport Programme**.[57]

Our latest analysis places transport as one of the biggest components of the hydrogen economy in future, with 2050 demand potentially reaching up to 140TWh.[58]

How will we develop and scale up hydrogen in transport over the 2020s?

We expect that the role of hydrogen in transport will evolve over the course of the 2020s and beyond. To date, road transport has been a leading early market for hydrogen in the UK. Going forward, we expect hydrogen vehicles, particularly depot-based transport including buses, to constitute the bulk of 2020s hydrogen demand from the mobility sector. Fuel cell hydrogen buses have a range similar to their diesel counterparts. Back-to-depot operating means hydrogen refuelling infrastructure can be more centralised and is likely to be compatible with distributed hydrogen production expected in this period. Concurrently, we will undertake a range of research and innovation activity which will focus on difficult to decarbonise transport modes, such as heavy road freight. As we demonstrate and understand these larger-scale applications we are likely to see more diversity in transport end uses in the late 2020s and early 2030s.

By 2030, we envisage hydrogen to be in use across a range of transport modes, including HGVs, buses and rail, along with early stage uses in commercial shipping and aviation. Our analysis shows there could be up to 6TWh demand for low carbon hydrogen from transport in 2030. Beyond this we expect to see an increased role for hydrogen in aviation and shipping decarbonisation which could become a large component of the overall hydrogen demand in the long term.[59] To meet CB6 in 2035 we estimate the demand from transport could be 20-45TWh.[60]

We recognise that the longer-term role for hydrogen in transport decarbonisation is not yet clear, but it is likely to be most effective in the areas where energy density requirements or duty cycles and refuelling times make it the most suitable low carbon energy source. Key challenges in this area include technology uncertainty, lack of existing hydrogen infrastructure, cost differentials and low numbers of hydrogen powered vehicles. Continued investment in research and innovation by government and industry will help to overcome these. As we learn more about ways in which hydrogen can be used in transport, we will need to put policy in place to support this technology rollout.

What are we doing to deliver?

Throughout the 2020s, government is taking forward a programme of development and demonstration of hydrogen technologies across different transport modes, to support commercial readiness and create real-world learning about the opportunities and barriers for any larger scale rollout.

Public transport

Approximately two per cent of England's local operator bus fleet is now zero emission – battery electric or hydrogen fuel cell.[61] **We will deliver the National Bus Strategy and its vision of a green bus revolution, including setting an end date for the sale of new diesel buses and the Zero Emission Bus Regional Areas (ZEBRA) scheme. ZEBRA will provide up to £120 million in 2021/22 to begin delivery of 4,000 new zero emission buses, either hydrogen or battery electric, and the infrastructure needed to support them.**

Rail is already one of the greenest ways of moving people and goods, and government is committed to making it even greener, in line with our net zero target by 2050. To decarbonise currently unelectrified parts of the network, electrification will likely be the best solution because electrified trains are faster, quicker to accelerate, more reliable and cheaper. There will also be a role for new traction technologies, like battery and hydrogen trains, on some lines where they make economic and operational sense.

Heavy Goods Vehicles

Large long-haul HGVs are the most challenging segment of the road sector for developing zero emission options due to their long journey distances and heavy payload requirements. Some vehicles are in constant use and therefore require fast refuelling to meet operational requirements. **We are investing up to £20 million this financial year in designing trials for electric road system and hydrogen fuel cell HGVs and to run a battery electric trial to establish the feasibility, deliverability, costs and benefits of these technologies in the UK.** To further support the shift away from fossil fuels, government is also consulting on the phase out date for the sale of new non-zero emission HGVs.

Shipping and aviation

Shipping and aviation are responsible for approximately five per cent of global emissions[62] and are some of the most difficult areas of transport to decarbonise.

Hydrogen in shipping

Low carbon hydrogen and hydrogen-derived fuels like ammonia and methanol are likely to play a crucial role in the decarbonisation of the maritime sector. Analysis commissioned by the Department for Transport (DfT) estimated that by 2050 there could be 75-95TWh of demand for hydrogen-based fuels (principally in the form of ammonia) from UK domestic and international shipping.[63] Coupled with decarbonisation of road and rail freight, hydrogen use in shipping could help create an end-to-end low carbon freight system from port to door.

The potential for adopting battery electric technology in the maritime sector is mostly constrained to domestic navigation: the size and weight required for battery powered ships means that their range is limited and they are not a compatible option with larger ship types.[64] Hydrogen could be used to decarbonise ships directly, through combustion or in fuel cells, or as feedstock for methanol or ammonia. Liquid ammonia is more energy dense than hydrogen meaning less storage volume is required on vessels, which may represent an effective option for larger ships on long-distance routes. Ammonia is also already internationally transported on ships so some infrastructure and supporting regulations are in place (although this ammonia is currently not low carbon).

Additionally, as set out in DfT's *Clean Maritime Plan*, research has estimated that the global market for the elements of alternative fuel production technologies in which the UK has a particular competitive advantage (for example, upfront design) could rise to around $11–15 billion per year (£8–£11 billion per year) by the middle of the century. If the UK were able to maintain its current export market share (estimated to be around 5 per cent of relevant global markets), this could result in economic benefits to the UK of around $490–690 (£360–£510) million per year by the middle of the century. This research also

found that while there are significant opportunities for the UK across all abatement options considered, the UK has the strongest competitive advantage in hydrogen and ammonia production technologies, alongside onboard batteries and electric engines.[65] **Government launched the £20 million Clean Maritime Demonstration Competition in March this year, which aims to accelerate the design and development of zero emission vessels in the UK and will lay the foundations for a network of technology demonstrations, fast-tracking maritime decarbonisation.**[66]

Government is also exploring the establishment of a UK Shipping Office for Reducing Emissions (UK-SHORE). This is a dedicated unit within the Department for Transport focused on decarbonising the maritime sector. UKSHORE will build on the success of the Clean Maritime Demonstration Competition, delivering a suite of interventions inspired by our experience with decarbonising other transport modes, looking at programmes such as the Office for Zero Emission Vehicles and the Future Fuels for Flight and Freight Competition.

UK-SHORE aims to transform the UK into a global leader in the design and manufacturing of clean maritime technologies and fuels such as hydrogen and ammonia. Government will continue to engage with industry to consider how the establishment of this programme in cooperation with UKRI and Innovate UK could unlock the necessary industry investment in clean maritime technologies, tackling supply- and demand-side barriers as well as developing infrastructure and consumer confidence.

Case Study: hydrogen in shipping

HySeas III is the final development stage of a programme to deliver a procurement-ready design for what the team hopes will be the world's first sea-going vehicle and passenger ferry to employ carbon-free hydrogen as its energy source. The vessel is planned to operate in and around Orkney and will use hydrogen which is currently being produced on the islands from renewable energy. The HySeas project is supported by approximately £10.8 million in funding, of which £8 million is provided by the European Union Horizon 2020 programme.

Hydrogen in aviation

The proportion of UK GHG emissions from aviation is expected to increase in the future as other sectors decarbonise. We need to tackle these emissions and are keen to do so in a way that capitalises on UK strengths in the aerospace and aviation sectors. To realise this, government has established the Jet Zero Council, a partnership between industry and government, to focus efforts on accelerating decarbonisation, including with an aim to deliver zero emission transatlantic flight within a generation. More recently, in July 2021 we published our 'Jet Zero Consultation' which seeks view on our proposed approach to reaching net zero aviation.

While there are technological challenges to overcome before hydrogen is used in aviation, interest from the aviation industry is significant. Airbus have announced their ambition to develop and launch a zero-emission large commercial aircraft, powered by hydrogen propulsion, by 2035.[67] Alongside this, through the *Aerospace Technology Institute (ATI) programme*, government is supporting a number of projects in this area.

Case Study: Aerospace Technology Institute funded aviation innovation

HyFlyer I and II (£15m): This landmark project provided ZeroAvia with funding to retrofit a small (six seat) aircraft with a hydrogen fuel cell powertrain, which completed the first-ever hydrogen powered flight of commercial-grade aircraft in September 2020. The flight also showcased a full zero-carbon emission ecosystem, with onsite hydrogen production via electrolysis. The funding is also supporting the company to scale up their technology for use in a 19-seat aircraft. ZeroAvia plan to have a commercial product by 2024.

FlyZero (£15m): An in-depth study to help UK aerospace develop a zero-carbon emission aircraft by 2030. The ATI-led project will bring together expertise from across the UK supply chain and universities to explore the design challenges and market opportunity of potential zero-carbon emission aircraft concepts and will be key in answering questions on the role and importance of hydrogen in decarbonising aviation.

H2GEAR (£27m): This ongoing project aims to develop a liquid hydrogen propulsion system – where liquid hydrogen is converted within a fuel cell system - for a sub-regional aircraft that could be scaled up to larger aircrafts. The programme is led by GKN Aerospace, alongside a number of industry and academia partners, from their Global Technology Centre in Bristol. GKN Aerospace believes the entry into service of hydrogen powered aircraft could be as early as 2026.

Additionally, hydrogen can be used to refine and produce Sustainable Aviation Fuels (SAF).[68] SAF could play a key role in emissions reduction in the short and medium term and the development of a SAF industry in the UK could see thousands of new jobs across the country.[69] **In March this year, we launched the £15 million 'Green Fuels, Green Skies' competition to support the production of first-of-a-kind SAF plants in the UK.** Government has set out its proposed ambition for SAF uptake in its SAF blending mandate consultation, which was recently published.[70]

A multi-modal place-based approach

Areas with particularly strong hydrogen potential could help to improve our understanding of the role of hydrogen in transport, drive local industrial strategies and jump start green recovery. **The UK's first 'Hydrogen Transport Hub' in Tees Valley will bring together government, industry and academia to focus on future hydrogen research and development, real world testing and demonstrations.** The Hub, supported by £3 million of initial government development funding this year, will bring a number of hydrogen vehicles to public roads and waterways, alongside the associated refuelling infrastructure. **In March this year we also announced that we will provide £4.8 million (subject to business case) to support the development of a hydrogen hub in Holyhead, Wales.** This will pilot the creation of hydrogen from renewable energy and its use as a zero-emission fuel in HGVs.

Case Study: a 'living lab' for hydrogen powered transport

Tees Valley Hydrogen Transport Hub: The hub will act as a living lab to understand hydrogen's role in decarbonising the transport sector, through large scale trials across different transport modes and use cases. The first of its kind in the UK, this project will comprise of a set of facilities for the production, storage and distribution of green hydrogen to supply a network of refuelling stations and support operational trials of hydrogen powered vehicles including road, waterways and aviation. The hub brings together government, industry and academia, and is expected to be fully operational by 2025 (subject to funding). This year the Tees Valley area will see various pilot projects of hydrogen vehicle demonstrations across modes and use cases including, but not limited to, forklifts, cars, buses, HGVs and marine vessels.

Supporting policy: the Renewable Transport Fuel Obligation

The Renewable Transport Fuel Obligation (RTFO) aims to increase the use of renewable transport fuels. Hydrogen produced by electrolysis using renewable electricity, as well as biohydrogen, for example produced through methane reformation of biomethane, are supported through the scheme. In March 2021, government published a consultation on the amendments to the scheme which sought views on a number of issues related to hydrogen support, including expanding the scope of the RTFO to make renewable fuels from non-biological origin used in maritime, rail and non-road vehicles eligible for support. Government's response to the consultation was recently published, with changes intended to come into effect from January 2022.

Hydrogen is a key alternative to the use of fossil fuels in transport – as well as in industry, power and heat – and will be essential to meeting our CB6 and net zero targets. We will continue to build on our strengths in research and innovation and expertise along the hydrogen value chain to fully realise the potential of hydrogen to support decarbonisation across end use sectors over the coming decade and beyond.

2.5 Creating a market

Key commitments

- We will set out further detail on the **revenue mechanism** which will provide funding for the Business Model in 2021.
- We will establish a **Hydrogen Regulators Forum** in 2021.
- We will assess **market frameworks** to drive investment and deployment of hydrogen, and provide an update in early 2022.
- We will assess **regulatory barriers** facing hydrogen projects, and provide an update in early 2022.
- We will complete an indicative assessment of the value for money case for **blending up to 20 per cent hydrogen into the existing gas network** by late 2022, and aim to make a final policy decision in late 2023.

The development and scaling up of each part of the hydrogen value chain will rest on policy frameworks to support the early expansion of a low carbon hydrogen market over the 2020s, and its later evolution to a dynamic, competitive, integrated and liquid market from the 2030s onwards.

Energy markets have evolved significantly over time, from the move to privatisation in the 1980s, to the transformation brought about by the Electricity Market Reform (EMR) programme set out in the Energy Act 2013, which set the path for rapid UK power sector decarbonisation. We have also seen the market respond to the decline in domestic gas production from the North Sea by building new natural gas terminals and pipelines to improve diversity of supply.

EMR and the changes in supply of gas happened against the backdrop of an already functioning market, albeit one that faced significant challenges to enable the long term decarbonisation ambitions set out in the Climate Change Act 2008.[71] Now, with more stringent CB6 and net zero targets, we need to reach for a new set of technologies like CCUS and low carbon hydrogen, which must be supported by complex new infrastructure systems. These newcomers to the UK energy landscape, as enablers for a deeply decarbonised and deeply renewable system, require a whole-system approach to development, with new support models to stimulate nascent markets.

There is much we can learn from the evolution of the gas and electricity markets, particularly from EMR. However, the hydrogen market is both complex and in its infancy. Reform of energy markets takes time, as will the growth of the hydrogen market. It would be near impossible to design a fully functioning hydrogen market for 2050 today – not

least because there remains significant uncertainty about its precise role and scale on this timeframe.

As the CCC's and our own analysis makes clear, rapid progress and learning by doing in the 2020s is vital. The roadmap at Chapter 2.1 highlights a challenging trajectory to meet our 2030 ambition and CB6 beyond this. While government intervention across the hydrogen value chain will be essential, we remain committed to market-led approaches that build and maintain competitive tension. Given the nascent state of the hydrogen market, it will be important that we learn and evolve, just as we have in the renewables market. In this, we will work closely with private sector partners to develop policy and signal next steps to attract the investment required. While this strategy package sets out the initial steps, there is far more to do, and we will continue to develop policy over coming months and years.

As set out in Chapter 1.5, a key strategic principle for government will be to take a 'holistic approach' to delivering our 2030 ambition and creating a thriving market for low carbon hydrogen. This means that any decision or action taken across the hydrogen value chain will inform and be informed by broader objectives and plans for the UK energy system, environment, economy and society including those set out in the forthcoming Net Zero Strategy. We will consider the implications of decisions and changes in the wider energy system, including dependencies on the deployment of energy infrastructure such as CCUS or offshore wind, as well as the impact of low carbon hydrogen on the wider system, for example in the potential for hydrogen to support integration of renewables with added benefits for energy security and resilience. This systemic approach to policy development is critical for success, both for developing a thriving hydrogen economy and to deliver our broader net zero objectives.

Our approach will therefore not be limited to the commercialisation and application of new hydrogen technologies. Government action will be required to put in place a wider policy framework covering regulations and, where needed, market support mechanisms in production, demand and supporting network and storage infrastructure, taking account of evolution in the electricity and gas markets and linkages to wider economic activity and networks. It will also be essential to raise consumer awareness, seek buy-in and to work through key issues such as policy governance and fair distribution of the costs and benefits of low carbon hydrogen.

Features of the emerging hydrogen market

The hydrogen market is currently limited to specific industrial settings, with high carbon production and use typically co-located. At much lower volumes, small scale electrolytic hydrogen is also starting to be used in the transport sector. Low carbon hydrogen value chains will differ according to location and circumstances, and be driven by production method, network infrastructure availability and demand profile. Creating a hydrogen market fit to serve a deeply decarbonised energy system will require concerted action to bring forward the necessary private investment across the value chain and enable the balance of supply and demand in a nascent market.

As set out in the roadmap at Chapter 2.1, the hydrogen market can be expected to grow and change significantly over the 2020s and out to the mid-2030s. For this evolution to happen, we will need to overcome a number of barriers across the value chain, especially in the early phases of market development. Consistent with challenges set out in previous sections of this strategy and in detail in the analytical annex, these barriers include:

- *High production and user costs*, relative to high-carbon counterfactuals.
- *Demand uncertainty*, overall and arising from specific end-use sectors – with BEIS analysis for CB6 suggesting 250-460TWh of hydrogen could be needed in 2050.
- *Policy and regulatory uncertainty*, which in this nascent market may deter investments across the value chain, especially as the regulatory framework is complex, including regulations relating to the environment, safety, markets, competition, planning, and specific end uses.
- *First mover disadvantage*, with early adopters taking significant initial risks but 'sharing' benefits with later entrants.
- *Technology uncertainty*, with most hydrogen technologies yet to be commercially demonstrated at scale.
- *Investor uncertainty*, both on the production and demand side, as well as for supporting network and storage infrastructure.
- *Lack of hydrogen* distribution and storage (covered in more detail in Chapter 2.3).

To overcome these challenges, government intervention will be required, both specifically to bring forward investment in new hydrogen production capacity in line with our 2030 5GW ambition, and more widely across the value chain through targeted support and

regulation. Such policies will seek to enable the low carbon hydrogen market to grow from fragmented initial stages to a highly integrated, competitive, transparent and liquid end state where hydrogen can compete against other technologies without support.

Different types of government intervention are likely to be required as the hydrogen market matures and expands, for instance to facilitate new end uses, noting that early uses may differ from those that will be most significant in the long term. The market failures and barriers faced by first-of-a-kind hydrogen projects operating in small, highly localised markets are unlikely to be the same as those faced by nth-of-a-kind projects operating in larger regional, national or even international markets. Greater price discovery and convergence, alongside cost reductions and learning by doing, will also affect the nature and structure of the market and policies that frame and support it. In time, the low carbon hydrogen market has the potential to become substantial, highly liquid and subsidy-free.

2.5.1 Developing the market framework for hydrogen

The market framework for low carbon hydrogen can be understood as the policies and interventions that directly or indirectly support or impede the supply and use of low carbon hydrogen, including the regulations that guide what markets it can be sold into, for instance in industry, power, heat or transport. This strategy and accompanying consultations, most notably on the Hydrogen Business Model, provide the first steps in developing the market framework for hydrogen. These are the steps we consider to be most important to kick-start the UK hydrogen economy, having worked closely with a wide range of stakeholders in recent years.

What are we doing to deliver?

In developing the market framework for low carbon hydrogen, we will need to balance policy certainty for investors with adapting and building flexibility to respond to future changes to the energy system. We will use the strategic principles outlined in Chapter 1.5 to inform the ongoing development of the market framework across the value chain.

Supporting innovation for first-of-a-kind projects

We are currently supporting hydrogen innovation through a number of mechanisms including the HySupply competitions, Industrial Fuel Switching competition and Hy4Heat programme. Supporting technical improvements and commercialisation of new hydrogen technologies will remain a key priority as government develops the £1 billion Net Zero Innovation Portfolio. Hydrogen project developers have to date also been able to access government co-investment through the £315m Industrial Energy Transformation Fund, £170m Industrial Decarbonisation Challenge and £10m Green Distilleries Fund which all support deployment of low carbon technologies including hydrogen.

Supporting hydrogen production

Our 2030 5GW ambition represents a step change in the scale of the UK hydrogen economy, and we are developing new policies to support the delivery of this ambition. In the near term, and as set out in Chapter 2.2 and the consultations published alongside

this strategy, we are proposing two key interventions that will help to bring down the costs of producing hydrogen relative to high carbon alternatives:

- The **Net Zero Hydrogen Fund**, designed to provide initial co-investment for new low carbon hydrogen production, with the aim of de-risking private sector investment and reducing the lifetime costs of low carbon hydrogen projects;

- Our **Hydrogen Business Model**, to provide longer term revenue support to hydrogen producers to overcome the cost gap between low carbon hydrogen and higher carbon counterfactual fuels, with the aim of enabling producers to price hydrogen competitively and helping to bring through private sector investment in hydrogen projects. **We intend to provide a response to our consultation on a Hydrogen Business Model alongside indicative Heads of Terms in Q1 2022.**

Demand-side interventions: carbon pricing, standards and sector-specific policies

While capital and revenue support for production will help to support investor confidence, it is likely that barriers to the development of the market will remain, most notably on the demand side. These can be mitigated through a range of other decarbonisation policies across different parts of the energy system. For instance:

- **Carbon pricing**, such as through the UK Emissions Trading Scheme (ETS) and Carbon Price Support (CPS), which send clear long-term signals that carbon will become an increasing cost for industry, thus promoting investment in low carbon technologies including hydrogen as a route to reducing these costs. We have already committed to exploring expanding the ETS to the two thirds of UK emissions not currently covered by the scheme as an important means of strengthening this long-term price signal, and will set out our aspirations to continue to lead the world on carbon pricing in the run up to COP26.

- A **Low Carbon Hydrogen Standard**, which can help to support the demand for low carbon hydrogen by providing confidence to end users that the hydrogen purchased is a low carbon alternative to existing fuels. We are also considering whether in time, this could also be used to underpin international trade. We are publishing a consultation on a UK low carbon hydrogen standard alongside this strategy, as explained in Chapter 2.2.

- **Sector-specific policies**, such as the Renewable Transport Fuel Obligation (RTFO) in transport, the Capacity Market (CM) in the power sector, or the Industrial Energy Transformation Fund (IETF) in industry, which can also support the use of low carbon hydrogen for particular sectors.

We will continue to engage with industry stakeholders and monitor progress as the market grows and our understanding of the pathways to CB6 and net zero continues to develop. In doing so, we will consider if further government action is required for the hydrogen market overall to evolve in line with our roadmap, and as we continue to review the existing energy policy landscape for consistency with CB6 and net zero.

Specifically, **we will undertake further work to understand and develop appropriate market frameworks to drive investment and deployment, considering how**

these should evolve over time to bring forward first-of-a-kind and nth-of-a-kind projects across the value chain, and transition to longer term competitive market frameworks. We will aim to publish initial conclusions and proposals in our next strategy update in early 2022.

Taking a whole-system approach

As we do this it may be appropriate to kick start the hydrogen economy through stimulation of early demand from sectors for which hydrogen may not be a significant decarbonisation solution in the longer run. For instance, blending hydrogen into the existing gas network could potentially facilitate access to a significant source of early demand, ahead of longer term decisions of the decarbonisation of heat in buildings (see gas blending box below). Hydrogen storage facilities may also play a role in providing greater demand-side certainty, especially when coupled with flexible power generation, which we will consider further as we assess future commercial arrangements for storage (see Chapter 2.3).

The coordination of supply and demand, particularly the sequencing and geographical location of production and end-users, will also be critical, driven to a large extent by the evolution of the hydrogen networks and storage infrastructure, but also wider system considerations. For instance, hydrogen producers or users in particular locations might provide valuable electricity grid balancing services.

In designing policy, it will be important to not create market distortions that would overly incentivise hydrogen relative to other decarbonisation routes. As and when we design new support schemes, we will need to carefully consider how they interact with the existing policy landscape. **We will work across government to highlight the potential role of hydrogen in the future energy system and consider whether and how this should be reflected in the design of wider energy markets and policies (such as the capacity market or the green gas support scheme).**

Creating a market: Gas blending to facilitate an early use case for hydrogen

Government is considering whether to support blending of low carbon hydrogen into the current gas network, to help with the initial development of the hydrogen economy. The *Ten Point Plan* set commitments to complete necessary testing of blending up to 20 per cent hydrogen into the gas grid by 2023.[72] Similarly, the *Energy White Paper* notes ambitious intentions to enable up to 20 per cent hydrogen blending on the networks by 2023 (subject to trials and testing).[73]

Use of hydrogen in our gas network is not new. Until the late 1960s, most of UK gas was 'town gas', which contained around 50 per cent hydrogen (mixed with methane and carbon monoxide). Town gas was typically manufactured locally from coal or oil, and consequently had a high carbon footprint and significant variability from one town to another.

The discovery of significant reserves of natural gas in the North Sea led to the rollout of an extensive national gas transmission and distribution system, meaning that today our gas system is much larger, more interconnected and better regulated. Today, around 85 per cent of households use gas central heating,[74] and a variety of industrial users have specific gas requirements.

Under the Gas Safety (Management) Regulations 1996, current hydrogen content in the gas networks is limited to 0.1 per cent by volume.[75] A deliberate effort to safely blend new gases into the existing gas network therefore requires evidence gathering and Health and Safety Executive (HSE) approval, prior to any live deployment.

Government and industry must continue to work together to overcome several critical technical, regulatory and commercial hurdles that will confirm whether blending *should and could* be an early use case for low carbon hydrogen.

Safety demonstrations, such as HyDeploy[76] and FutureGrid,[77] are underway to explore the potential for blending at distribution and transmission network pressures, in addition to investigating impacts on end use. The current phases of both trials are due to conclude in 2023. A comprehensive value for money assessment is required to assess the costs and benefits of blending. This will include evaluating crucial timings envisaged for potential future use of 100 per cent hydrogen for heat. The current gas system is not yet designed to accommodate hydrogen. Consequently, government is working closely with key delivery partners to assess the regulatory, physical and system changes required across the gas market to facilitate blending.

While blending could yield potential strategic benefits, some of which may be contingent on wider developments in the hydrogen value chain and existing gas market, there are also limitations. The relative balance between these may change as we continue to understand the pathway to CB6 and net zero, and as the market for hydrogen matures.

Strategic role	Potential benefits	Limitations and contingencies
Supporting low carbon hydrogen production & early development of hydrogen economy	Blending could facilitate access to a significant source of demand for early low carbon hydrogen producers, potentially functioning as a useful sink for excess production (as an 'offtaker of last resort'). We recognise that blending could offer security for hydrogen production investment decisions, by providing a commercial option to sell hydrogen for gas consumer use.	As there are other 'demand offtakers' for hydrogen (such as in industry or power), depending on the blending value for money case, alternative offtakers might provide a preferable longer term use for hydrogen.
Transferable insights for future use of 100 per cent hydrogen for heat	Blending hydrogen into existing gas networks could accelerate some technical, regulatory and commercial changes that may facilitate a smoother transition to the potential use of pure hydrogen as a heating fuel. This might include reforming gas consumer billing methodologies or potentially altering governance of the Gas Safety (Management) Regulations 1996. Blending may also improve consumer awareness of the benefits and ease of using hydrogen as a heating fuel.	A use of 100 per cent hydrogen for heating scenario is still not certain and even if the UK proceeds with this option, further enabling changes would be required across all technical, regulatory and commercial areas.
GHG emissions reductions	Low carbon hydrogen is less carbon intensive than natural gas, and thus blending could help decarbonisation of the existing gas grid in the near term.	Hydrogen has a lower volumetric energy density compared to natural gas. This means that a significantly larger volume of hydrogen would need to be blended and deployed to make substantial carbon savings. Blending is not a sufficient route to long term gas decarbonisation required by net zero.

Government recognises that, should blending be rolled out, industry will need early sight of how it should be implemented. We are proposing five principles for delivery:

- Blending low carbon hydrogen across the existing gas network, or parts thereof, would remain within safe limits set by the HSE (likely up to 20 per cent by volume); and any proposed changes to gas quality and infrastructure would meet all safety requirements.

- Any proposed changes to gas quality and infrastructure should maintain existing system, pipeline, and consumer appliance operability.

- Blending should not prohibit a secure supply of gas for consumers.

- Any costs to consumers should be affordable (ensuring value for money).

- Blending could support initial development of the low carbon hydrogen economy, but blending is not a preferred long term offtaker.

Government, Ofgem, existing gas networks and wider industry must continue to share information and work closely on evidence gathering and aligning understanding on safety, physical roll out models and value for money. Forthcoming actions range from:

- Addressing safety, operability and technical concerns.

- Proposing an optimal, practical model for blending.

- Conducting a value for money assessment.

- Comparing the merit of blending versus other end uses for low carbon hydrogen.

- Creating a regulatory and commercial framework, for example – a new billing methodology.

This is essential work that we will prioritise in the coming years.

If there is a value for money and safety case for blending, government's intention is to enable blending of hydrogen into the existing gas grid at the earliest from 2023, as a measure to help bring forward early hydrogen production.

We will engage with industry and regulators to develop the safety case, technical and cost effectiveness assessments of blending up to 20 per cent hydrogen (by volume) into the existing gas network. Ahead of the completion of safety trials, we aim to provide an indicative assessment of the value for money case for blending by autumn 2022, with a final policy decision likely to take place in late 2023.

Ensuring appropriate funding mechanisms to support a developing hydrogen market

Low carbon hydrogen is currently more expensive than counterfactual fuels, and the additional costs cannot be directly passed onto customers if hydrogen is to be a competitive alternative. Funding must come from elsewhere to make hydrogen production and use commercially viable, and deciding how this is paid for and who bears the cost is a key question that must be addressed. The complex nature of the hydrogen market means that the impacts of a chosen funding mechanism must be considered across a range of different end use sectors and consumers, including their ability to absorb these costs, and the impact that additional costs would have on demand. **Further details of the revenue mechanism, which will provide funding for the Hydrogen Business Model, will be provided later this year.**

2.5.2 Ensuring a supportive regulatory framework

The regulatory framework as it relates to hydrogen is broad and complex, including rules and regulations relating to the environment, safety, markets, competition, planning and specific end uses. While early projects can be expected to operate within existing regulatory regimes, new rules and regulations may be required to facilitate the further expansion of the market and maintain competitive pressure over the course of the 2020s and beyond, especially should hydrogen networks connect to the existing gas network in the future, for instance, to enable blending or grid conversion.

What are we doing to deliver?

Government is working with regulators and industry to develop a common understanding of how current regulation supports or impedes the production and use of low carbon hydrogen – for instance, through the working group on standards and regulations under the Hydrogen Advisory Council. Projects such as HyLaw have analysed the legal and administrative processes applicable to hydrogen in several countries and identified the legal barriers to the deployment of hydrogen applications in the UK.[78]

Through such channels, we are considering both the immediate regulatory barriers to the initial development of the hydrogen economy, but also the broader regulatory framework for hydrogen, and how it will need to evolve as the hydrogen and wider energy markets develop over the course of the 2020s, to the mid-2030s and out to net zero in 2050. This work will allow government to plan and prioritise regulatory changes and provide clarity on the roles and responsibilities of different regulators. In doing so, we will consider and address four overarching and interdependent regulatory issues for the hydrogen economy.

Addressing regulatory barriers facing first-of-a-kind hydrogen projects

First-of-a-kind projects can act as critical innovators in the development of the technologies and policy interventions that will underpin the future hydrogen economy. However, they may encounter unexpected regulatory barriers, for instance relating to safety, planning, licensing or access to end use markets (for example, different regulations and regulators for households versus industry, transport versus heat). Such unforeseen barriers can significantly hinder early project development and related innovation.

Building on initiatives such as HyLaw and the experience of early industrial 'pathfinder' projects (see Chapter 2.4.1), **government will continue to work with industry and regulators in the early 2020s to identify and address regulatory barriers faced by first-of-a-kind hydrogen projects and consider changes needed to unlock hydrogen investment and deployment across the value chain. We will aim to publish initial conclusions and proposals in our next strategy update in early 2022.**

Using regulation to unlock access to new markets for hydrogen

Regulatory changes may also be required to unlock new markets for hydrogen (such as potentially mandating hydrogen-ready appliances in some areas), or to address regulatory barriers that limit the option of low carbon hydrogen (such as changing the Gas Safety Management Regulations (1996) to allow for hydrogen blending into the gas grid).

Government will continue to work with industry and regulators to consider what regulatory changes may be appropriate across the hydrogen value chain, in line with other commitments made in this strategy.

We will also work across government to highlight the potential role of hydrogen in the future energy system and consider whether and how this should be reflected in wider regulatory and policy changes (such as any future changes to the Gas Act 1986).

Identifying who should regulate an evolving future market for low carbon hydrogen, and how and when

As hydrogen networks expand out of initial clusters in the 2020s, and with critical decisions being made on blending hydrogen into the existing gas grid by 2023 (subject to trials and testing) and on the potential for use of 100 per cent hydrogen in heating in the mid-2020s, the nature and scale of hydrogen networks may alter significantly, potentially reaching right into people's homes. This would have important implications for the applicable regulatory and legal frameworks, with bespoke arrangements likely to be required, overseen and administered by new statutory bodies or existing ones with new powers.

The applicable regulations in the initial stages of market and network expansion may need to evolve as the market grows and matures. Identifying when changes are needed to enable the market to progress through phases of integration and expansion will be critical, and likely long lead-in times for regulatory changes will need to be taken into account. While we expect some regulatory changes will be required by the mid-2020s to support early network expansion, the long-term arrangements will likely not be in place until the late 2020s. Working through these issues will be an iterative process, and **we will formalise our engagement through the creation of a Hydrogen Regulators Forum, with representation across the relevant regulatory areas (including environmental, safety, markets, competition and planning).**

Ensuring that the potential role for hydrogen is considered in broader reviews of regulation

Any action to support and frame the hydrogen economy will need to be reflected in the broader energy system. This includes the rules, regulations and governance that guide how the energy system functions. As outlined in the *Energy White Paper*, there are numerous pieces of legislation and guidance that will need to be reviewed as the UK transitions to an affordable, secure and reliable energy system which delivers our net zero ambitions – for instance in relation to gas, electricity, CO_2 transport and storage and planning. **We will work across government and with regulators to ensure that the interlinkages between hydrogen and broader governance and regulatory changes are appropriately considered. We will consult this year on the institutional arrangements governing the energy system over the long term, including system operation and energy code governance.**

Developing a regulatory framework for the hydrogen economy that incentivises investment, provides long term certainty, maintains competitive pressure and supports integration with a wider net zero energy system will take time and work. Government will continue to work with regulators and industry to ensure that this regulatory framework can evolve over time in a way that supports our 2030 ambition and positions the hydrogen economy for scale up beyond this for CB6 and net zero.

2.5.3 Raising awareness and securing buy-in

Hydrogen has been used in the UK for many years, as described in Chapter 1, but its future role will be very different. Many potential users are not yet aware that hydrogen could be a low carbon solution for them. Even those who are aware would not find it easy to identify a reliable source of hydrogen, or its cost and carbon intensity. Similarly, many of the technologies users would need to switch to hydrogen, such as boilers and trucks, are not yet commercially available. This means that a critical part of our action in the early 2020s to create the market for hydrogen will be to ensure that energy consumers and businesses understand the potential of low-carbon hydrogen and how it operates, and to provide assurance that its development and rollout are underpinned by systems and frameworks appropriate for any energy carrier and related technologies.

What are we doing to deliver?

The transition to any new low carbon technology brings both opportunities and challenges for different stakeholders. We will draw on lessons learnt from raising awareness of other new and low carbon technologies, such as smart meters and electric vehicles, to ensure businesses and consumers can access and drive forward the low carbon hydrogen economy.

Additionally, we will work with industry to maximise the positive outcomes for the climate and environment that the growth of a low carbon hydrogen economy could bring, including for air quality, and will ensure that any potential trade-offs between the two are minimised. For example, we will support industry to work with the Environment Agency and other regulators to reduce the creation of nitrogen oxide (NOx) emissions that the combustion of hydrogen in an engine or boiler creates, helping to deliver on our air quality targets to deliver cleaner air for all.

We recognise the need for targeted engagement going forward to understand and work through key priorities for industry, businesses, civil society and households to secure buy-in and enable the use of low carbon hydrogen across different parts of the energy system. To help with this, we have established the Hydrogen Advisory Council which reflects a cross section of expertise on low carbon hydrogen across the value chain. We are also engaging with a wide range of stakeholders outside of this forum, recognising the importance of different perspectives in shaping this nascent policy agenda.

Broad and early stakeholder engagement allows for important public discourse on different aspects of our 2030 ambition and broader plans to deliver CB6 and reach net zero. We will continue to engage citizens and use the expertise of others to inform policy development by considering conclusions of citizen's assemblies which provide feedback from a representative sample of the UK (such as Climate Assembly UK's report, 'The Path to Net Zero).

This approach has already yielded important insights with technologies associated with low carbon hydrogen production. For example, in collaboration with UKRI and Sciencewise, last year we commissioned a public dialogue study to explore citizens' perceptions towards CCUS at both a local and non-local level. Public engagement will help us to understand different perspectives towards the substantial infrastructural and behavioural changes that are needed to decarbonise our energy system over the next 30 years, including in relation to the potential role of hydrogen.

While we recognise the crucial role that government can play in raising public awareness of the importance of decarbonising our energy system, including through low carbon hydrogen, we are mindful that this will be most effective carried out collaboratively with local communities to understand the priorities of and opportunities for different stakeholders. These groups are well placed to help us assess the fairness and affordability of different policy decisions to support the hydrogen economy as it grows.

Regulators and industry will also be engaging in activity to raise awareness for potential new uses case for hydrogen. Through the safety workstream of the Hy4heat programme, government is working with HSE on a project to assess the safe use of hydrogen gas in certain types of domestic properties and buildings (detached, semi-detached and terraced houses of standard construction), as part of preparation for the first community trials using hydrogen as a heating source.

The Hy4heat programme, in collaboration with NGN and Cadent, is also supporting the construction of two unoccupied homes in Gateshead that will feature Hy4Heat-funded prototype boilers, hobs, cookers, fires and meters to showcase the potential use of 100 per cent hydrogen for domestic heating. Members of the public will be able to see how these appliances compare with like-for-like ones that run on natural gas. Building on this learning, we are delivering a programme of work to assess the feasibility, costs and consumer experience of 100 per cent hydrogen heating (see Chapter 2.4.3). These include consumer trials which will be key to understanding how consumers could experience hydrogen heating.

The government sees this strategy as a significant step towards improving awareness, both of the potential role that hydrogen can play in decarbonising our energy system, and of the challenges involved in bringing this about. We will continue to explore opportunities for dialogue and information sharing on the challenges and opportunities for low carbon hydrogen, including in relation to other low carbon technologies. Public engagement is an important priority for government in the run up to COP26, and as we look to publish our forthcoming Net Zero Strategy.

Chapter 3:
Realising economic benefits for the UK

Key commitments

- We will prepare a **Hydrogen Sector Development Action Plan**, including for UK supply chains, by early 2022.
- We will establish an **Early Career Professionals Forum** under the Hydrogen Advisory Council.
- We will support hydrogen innovation as one of the ten key priority areas in the **£1bn Net Zero Innovation Portfolio**.
- We will work with the Hydrogen Advisory Council Research & Innovation Working Group to develop a UK **hydrogen technology R&I roadmap**.
- We will deliver as one of the co-leads of Mission Innovation's new **Clean Hydrogen Mission**.

The UK's geography, geology, infrastructure and expertise make it particularly suited to rapidly developing a low carbon hydrogen economy. This offers a great opportunity for companies, communities and individuals. This chapter sets out our plans to maximise the economic benefits to the UK from this shift – supporting jobs and regional growth, making the best of our research and innovation strengths, and ensuring that businesses across the country are in a position to tap into the growing global hydrogen market.

The hydrogen economy is in the very early stages of development in the UK and globally. This presents an opportunity to put a focus on economic benefits at the heart of our approach from the outset as we look to deliver our 2030 ambition and contribute to achieving our CB6 and net zero targets.

We can draw on lessons from the development of other low carbon technologies to ensure that our companies, communities and individuals can be at the forefront of this opportunity – promoting world-class, sustainable supply chains and creating high value, skilled jobs. We will also make the UK an attractive place to invest in hydrogen and seek to maximise the export potential of our technologies and expertise. In doing so, we will support the government's *Plan for Growth*, driving local and regional opportunities, and helping to level up across our industrial heartlands and throughout the UK.

We will work in partnership with industry, the academic and research and innovation community, devolved administrations, local authorities, workers and civil society to harness the best of the UK's skills and capabilities. We will share these with – and learn from – expertise elsewhere, and capitalise on our world-leading academic and industrial research and innovation base.

Government will work to bring together the various existing and emerging businesses critical to enabling the hydrogen economy. Some of these will be well-established firms

in the transport, industrial and oil and gas sectors; others will be emerging innovators designing and building fuel cells, electrolysers, and new components for the distribution and storage of hydrogen.

We want to see UK companies at the forefront of the growing global hydrogen market, and we are developing policy that will attract and secure investment in a pipeline of British projects, driving rapid progress to foster our exportable strengths and get ahead in the global market.

Analysis[79] suggests that in 2030 the UK hydrogen economy could be worth £900m and support over 9,000 jobs. Around a quarter of these jobs could be driven by British supply chain exports.

By 2050, under a high hydrogen scenario, the hydrogen economy could be worth up to £13 billion and support up to 100,000 jobs, with exports growing in relative importance.

3.1 Building a world class supply chain

Government will work to promote the growth of world-class, sustainable supply chains to underpin the deployment of early commercial scale UK hydrogen projects over the 2020s, and to be ready to support expansion of the sector from the 2030s.

The UK is well positioned to grow and develop supply chains across the full low carbon hydrogen value chain, from production, through to transportation, distribution and storage, and across various end uses in industry, power, heat and transport. These supply chains will be vital to underpinning our vision of growth in the hydrogen economy across the 2020s, and to position it for significant ramp up in the 2030s in line with CB6 and net zero.

To make sure that the UK can capitalise on these opportunities, we have carried out an initial assessment of current UK low carbon hydrogen supply chain capability and strengths, to identify opportunities and barriers to companies being able to thrive and support the full hydrogen value chain as it develops in line with our 2020s roadmap (see Figure 3.1 below).

Seizing the opportunity

We will work with industry, academia and other stakeholders to build on insights from other energy sectors to assess what actions government, industry and the research and innovation community could take to seize the supply chain opportunities presented by the early development of a low carbon hydrogen economy, and for UK businesses to position themselves at the forefront of the hydrogen economy. **We will set out more detail in a Hydrogen Sector Development Action Plan by early 2022.**

We will learn lessons from the development of the UK's world-leading oil and gas sector, driven in part through measures introduced in the 1970s. Similarly, we will draw on the expansion of other low carbon sectors, such as offshore wind, where early opportunities for UK investment, regional growth and job creation were not built in and capitalised on from the start, even while the UK has become a world leader in deployment.

Figure 3.1: UK supply chain development over the 2020s

Early 2020s	Mid 2020s	Late 2020s onward
• British supply chain companies lay the foundation to support our vision for the hydrogen economy in the near and long term. • The UK builds on its strengths in electrochemical technologies (fuel cells and electrolysers). British companies are exporting these technologies to markets in Europe and SE Asia. • Domestically, these are deployed in small-scale electrolytic production projects and in transport. • World-leading supply chains supporting other sectors, such as oil and gas, pivot towards supporting the hydrogen economy, offering opportunities to make use of UK skills, capabilities and technologies.	• The UK has the opportunity to deploy blue hydrogen projects, linked closely to the development of CCUS supply chains, as set out in the CCUS roadmap, taking advantage of UK CO_2 storage potential. • Supply chains across the value chain gear to support scaled-up deployment, and are positioned to support future growth of the domestic hydrogen economy. • UK continues to build on its world-class innovation. For instance, domestic hydrogen boilers which have the potential to serve the domestic market.	• Continued growth in low carbon hydrogen production, complemented by growing UK strengths in distribution and end-use markets such as in vehicles and industrial applications. • UK takes advantage of its natural assets, for instance in seizing opportunities for hydrogen storage. • UK supply chains and skills base are well positioned to support accelerated domestic deployment in support of net zero in the 2030s and beyond, and to seize opportunities to export technology, expertise, and hydrogen itself. • The hydrogen sector plays an important role in supporting other sectors, such as construction, automotive and steel, to anchor their supply chains in the UK by making it possible for them to decarbonise and develop a low-carbon proposition that will ultimately be exportable.
• Throughout, the breadth of the hydrogen value chain offers opportunity to seize on UK expertise in other sectors, such as high-end manufacturing, oil and gas, renewables, chemicals, safety, engineering, procurement and construction management (EPCm) and our functional strengths of planning, legal, professional and financial services.		

In doing so, we will also focus on developing the next generation of technologies that will help fill the gaps in the supply chain, reduce costs and put the UK on a footing to grow at scale in the 2030s.

This work will include supply chains that currently support high carbon industries, which have the opportunity to pivot and build on their base capabilities and expertise to meet the needs of the UK hydrogen sector, as well as internationally. This will not be limited to CCUS-enabled hydrogen but will include strengths in process engineering, offshore engineering and re-purposing of offshore assets, and gas safety management. The new UK Energy Supply Chain Taskforce[80] will focus on ensuring UK supply chain companies can take advantage of clean growth opportunities in the UK and overseas.

The oil and gas sector's voluntary commitment through the *North Sea Transition Deal* to aim towards 50 per cent local content across the lifecycle of projects, including for hydrogen, will help safeguard long-established UK supply chains – and world-leading skills, capabilities, and innovation – that will be crucial to realising both the decarbonisation and economic benefits of the UK's transition to net zero.

Our expectation of industry

We will seek to introduce economic benefit assessments into the Net Zero Hydrogen Fund and Hydrogen Business Model. Consultations on the NZHF and the Hydrogen Business Model are taking place alongside the publication of this strategy. Our expectation is that hydrogen developers across the full value chain will work to ensure that competitive UK companies, including SMEs, are in a fair position to bid into hydrogen projects.

In establishing these assessment criteria, we will recognise that the hydrogen market is in its infancy and that intervening too firmly for first-of-a-kind projects could stifle cost-competitive growth. Over time, however, we anticipate that hydrogen will follow in the footsteps of established sectors like offshore wind and oil and gas to be able to put in place bold commitments to UK content.

Such measures might follow along the lines of the changes to the renewables supply chain plans being introduced through the Contract for Difference (CfD) allocation process. These will require a supply chain plan to be submitted to the Secretary of State before participation in CfD auctions, building on the offshore wind sector's voluntary commitment to 60 per cent local content through the *Offshore Wind Sector Deal*.

We will actively monitor the extent to which competitive UK businesses are benefitting as the hydrogen sector matures. If necessary, we will consider what options are open to ensure a fair playing field that includes UK businesses. **We will set out more detail on this in our Action Plan.**

Project visibility

To be successful, low-carbon hydrogen supply chains will also need to have good visibility of the opportunities ahead, across the full hydrogen value chain. **We will work with industry to improve visibility of the low carbon hydrogen project pipeline across the supply chain, learning from the success of initiatives in other low carbon sectors.**

3.2 Creating jobs and upskilling industry

Developing a hydrogen economy is a key component of the opportunity offered by our net zero target to transform the UK's industrial regions, attract investment, and create secure, good quality green jobs across the UK. Developing this nascent sector will require existing and important new skills to be available in the right place at the right time. We will work with partners to identify skills requirements and intervene if necessary, including to support workers from transitioning high carbon sectors.

Creating a successful hydrogen sector could support 9,000 direct jobs across the UK by 2030, with up to 100,000 supported directly by 2050.

These jobs, with additional indirect and induced[81] employment benefits, will help drive local economic growth and support the delivery of government's commitment to level up the UK.

Ensuring the right skills are available in the right place at the right time

Ensuring that the UK has the right skills and capabilities will be critical to achieving our hydrogen ambition.

As part of our work to develop the low carbon hydrogen sector, we will assess the opportunities for hydrogen employment across the UK. Over the next year, in collaboration with stakeholders, we will work to understand the profile of required skills over the 2020s and into the 2030s, in line with our roadmap set out in Chapter 2.1. **We will work with industry, trade unions, the devolved administrations, local authorities, and enterprise agencies to support sustained and quality jobs and ensure that there is effective and targeted investment in relevant skills.**

Creating good-quality[82] jobs in the hydrogen sector, particularly where these are in our industrial heartlands, will make a significant contribution to ensuring people do not have to relocate to succeed. As set out in the *Plan for Growth*, we will catalyse centres of excellence and help people connect to opportunity as a way to drive regional and local growth.

We believe that initiatives to invest in growing the skills base are best when led locally, to ensure skills are tailored to demand. The government's *Skills for Jobs: Lifelong Learning for Opportunity and Growth White Paper*[83] recognises that there are skills gaps at higher technical levels which might affect our ability to grow the green economy. Investing in these skills at both a local and a national level will be critical. **We will work with industry, education providers and local and regional authorities to explore opportunities for relevant skills programmes, including apprenticeships and re-skilling programmes.**

In doing so, we will work to ensure that the recent recommendations from the *Green Jobs Taskforce*[84] will inform the UK's forthcoming Net Zero Strategy, many of which are pertinent to the hydrogen sector. These recommendations aim to:

- Ensure the UK has the immediate skills needed to kick-start and deliver a green recovery.
- Develop a long-term plan to chart out skills requirements ahead of net zero.
- Ensure jobs in the green economy, such as the hydrogen sector, are high quality and inclusive.
- Support opportunities for workers in high carbon sectors, supporting them through the transition to zero carbon sectors.

To attract and retain talent, we will also work with the sector to ensure that equality of opportunity is considered from the outset. We are mindful of the *Offshore Wind* and *Nuclear Sector Deals'* diversity ambitions[85] and see no reason why the hydrogen sector cannot be at least as ambitious.

In support of this, **we will set up an Early Career Professionals Forum under the Hydrogen Advisory Council.** As an emerging sector, it will be important to ensure that early career professionals in the hydrogen economy are engaged and able to advise government.

Re-skilling workers from high carbon industries

Hydrogen provides an opportunity for those who have previously worked or are currently working in high carbon sectors to transition to support the green industrial revolution.

As an example, Oil & Gas UK has estimated that, between 2018 and 2030, the number of jobs directly and indirectly supported by the UK's offshore oil and gas industry could reduce from 147,000 to around 105,000.[86] Many skills in this industry will be transferable to clean growth industries, and hydrogen will provide significant opportunities – including project management, process engineering, repurposing of infrastructure and gas safety.

The recent *North Sea Transition Deal*[87] committed the government to continue to champion the role of the oil and gas sector and its workforce in the energy transition, supporting work on the sector's Integrated People and Skills Plan. In March 2021, the government announced £27m of funding for the Aberdeen Energy Transition Zone and £5m for a 'Global Underwater Hub', which will help support the industry's transition to renewable and low carbon energy technologies such as offshore wind, hydrogen and CCUS. We will work to support other initiatives in relevant sectors, and will support work to ensure portability and mutual recognition of professional qualifications to enable people to transition to new sectors such as hydrogen without re-certification.

We will work with industry and others to support workers in need of training so that they can access the new jobs that will become available. We will also work collaboratively with industry and education providers to explore what high-intensity up-skilling and re-training opportunities could be provided.

We will continue to support the work of the Energy Skills Alliance (ESA) established in 2019, which is working to produce a clear forecast of energy skills in the short term, deliver